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Ramifications of Raman Effect

Dr. C. K. Subramanian*

Introduction:

The year 1988 happens to be the Diamond Jubilee year of the discovery of the Raman effect but also the birth centenary year of Sir C V Raman.

Hence it is fitting occasion to write about The Raman Effect and its ramifications as a fitting tribute to pay homage to the memory of "this titan among Indian Scientists", who strode the world of sciences like a colossus. In the following article though there are several variant techniques of Raman Spectroscopy evolved, only very important findings are highlighted. Certain devices like Spin-flip Raman sources etc., are omitted.

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*A review based on the talk given at CECRI Karaikudi on 28.2.1988 (National Science day).

Raman Effect

While studying the molecular scattering of light at Calcutta Sir C V Raman discovered a new phenomenon known after him as The Raman Effect. The observation of blue opalescence of the Mediterranean sea during his voyage to Europe in 1921 initiated him to have detailed investigation on light scattering at Calcutta later.

When a beam of monochromatic radiation passes through a transparent medium some of it is scattered by the vibrating and/or rotating molecules of the medium. Most of the scattered radiation is of the same frequency (Rayleigh Scattering) and of it changes frequency (new light scattering observed by Raman). The latter observation by C. V. Raman on 28th February 1928 later came to be known as Raman Effect. The frequency shifted spectral lines arise due to the change in polarizability of the molecule and it represents the molecular disortion under the electric field of the incident electromagnetic radiation. Otherwise this is essentially an inelastic scattering of light by molecular vibration and/or rotation arising due to the modulation the electric susceptibility (polarizability) of the above mentioned molecular vibration and/or rotation.

The mechanism of Raman effect can be explained qualitatively as follows. The molecule when irradiated by an electromagnetic radiation (visible or

20-3-1953
yours sincerely
C. V. Raman

Sir 'C. V. Raman'
1888–1970

uv radiation), two types of emission occur. In one the ground state is completely restored emitting radiation of same wavelength as the incident (exciting) radiation is known as Rayleigh scattering. Another transition on either side of the exciting radiation (frequency shifted) correspond to the inelastic scattering arising from the molecules interacting with the electric field associated with the incident monochromatic radiation. The inelastic contributions are further subdivided: those scattered frequencies smaller than incident radiation known as Stokes components and while the scattered radiation larger than the incident radiation known as anti-Stokes components. Each scattered photon in the Stokes component is associated with a gain in energy by the sample, while the sample losses energy in each scattered photon in the anti-Stokes component.

The above experimental technique is a powerful tool for scientists in elucidating the structure of molecules, biomechanism in biomolecules etc. through the role played by various groups of molecule making the molecular system. The scattered radiation intensity is 10^{-4} times smaller than the incident exciting radiation and hence Raman spectra of molecules are very weak. However, after the advent of lasers, the situation has become more favourable to record the Raman spectra with ease with sample size of a few microgram or microlitre. Moreover the Raman spectra has been made complex due to the linear and nonlinear interactions of molecules with the intense $10^9 V\ m^{-1}$ electric field associated with the exciting laser radiation. Thus new analytical techniques had been developed to study molecular systems, surfaces etc., in detail giving the scientists a deep insight into various physical and chemical mechanisms and principles involved.

As mentioned earlier when the electric field intensities of the incident radiation exceeds 10^9 volt m^{-1}, the nonlinear contributions to the induced dipole (polarizability) start to become significant, and that such electric field intensities are associated with the monochromatic radiation produced by giant pulse lasers. Many new phenomena arise from the nonlinear interaction of a system with intense monochromatic radiation. All phenomena involve changes in the wavenumber of laser radiation as a result of its interaction with the molecular systems and so are regarded as varients of the Raman effect. This generic relationship is reflected in the names which have been adopted for these new effects; the hyper Raman effect; the inverse Raman effect; the stimulated Raman effect; coherent anti-Stokes Raman scattering (CARS) and Raman induced phase conjugation spectroscopy. Each of these effects involves new principles and hence novel applications are possible and new information can result.

a) Resonance Raman Scattering

In a Raman process from a molecular system, an incident photon is destroyed, a scattering photon is created and the molecular system undergoes a transition from the initial state to a final state. This process is coherent and therefore these events are not independent and resolvable i.e., a process in which three events occur invisibly. If the excitation frequency is close to or in resonance with an available excited state is the process is called Resonance Raman scattering (RRS). By varying the excitation frequency (using tunable lasers or source of light) from off resonance to on resonance condition can be achieved. Thus obtained Raman spectra has striking changes in the intensity, temporal behaviour and frequency distributions.

b) Surface Enhanced Raman Spectroscopy (SERS)

Intense Raman signals were observed from pyridine adsorbed onto electrochemically roughened silver electrodes. The enhancement of Raman signal is attributed finally to that of the preparation of a microscopically rough surface and was concluded as a necessary prerequisite to observe SERS.

So far we were discussing the linear interaction of the electromagnetic radiation with the molecular system. Let us now devote our attention to what type of result oriented phenomena occur when the electric field intensity of the incident radiation exceeds 10^9 volts m^{-1}. It is found that new phenomena arise from the nonlinear interaction of the molecular system with intense monochromatic radiation akin to the normal Raman effect. Hyper Raman; inverse Raman; stimulated Raman (SRS) and coherent anti-Stokes Raman Scattering (CARS) involve changes in the wave number of Laser radiation as a result of its interaction with a molecular system and so are to be regarded as variants of the normal spontaneous Raman effect. This generic relationship is reflected in the names which have been adopted for the new effects.

Hyper Raman Effect

This effect arises when focused ν_0 (6943.3Å) laser beam (pulsed nanosecond duration) interacts in any direction of the samples gives rise to lines at 2 ν_0 (347?A) and at $2\nu \pm \nu_M$ where ν_M is the molecular vibrations. This method provides a novel tool to observe weak Raman lines arising from poor scatters like water molecules.

Stimulated Raman Effect (SRS)

When monochromatic radiation from a giant pulse laser of sufficiently large irradiance is incident upon a scattering system hyper Raman scattering is superceded by a new phenomenon viz., stimulated Raman Scattering. SRS depends on the direction and manner of illumination. The giant pulse laser radiation is focused into

sample and the scattering observed along the laser beam direction in the forward direction at a small angle.

(1) SRS differs from the normal Raman scattering not only in its wave number pattern and angular dependece but also to its intensity.

(2) In SRS only selective excitation of molecular vibration occurs viz., Raman active modes.

(3) The first stokes line in SRS rapidly grows in intensity to act as a power source and chain reaction occurs for the formation of further lines.

(4) The generation of the anti stokes line does not arise as a result of downward transition from a populated upper state as in normal Raman effect but created at the expense of laser photon.

(5) High conversion efficiency and hence new laser lines can be generated using suitable molecular media thus increasing the number of laser lines in the electromagnetic spectrum for resonance absorption studies.

Inverse Raman Effect

If a molecular system is illuminated with a giant pulse laser beam of wave number $\bar{\nu}_0$ and a continuum covering the wave number range $(\bar{\nu}_0 + 3500)$ cm^{-1}, absorption bands are observed in the continuum at wave numbers $\bar{\nu}_0 + \bar{\nu}_M$ etc: where ν_M is a Raman active vibration mode of a molecular system. This method offers a method of recording Raman spectra of short lived molecular species of the order of 10^{-8} to 10^{-11} seconds. There is no restriction in the direction of observation as in SRS and hence it has great promise to study short lived species, but the experimental procedure is not easy.

Coherent Anti–Stokes Raman Scattering (CARS)

If a coherent radiation of wave number $\bar{\nu}_1$ is mixed in a molecular medium with coherent radiation of wave number $\bar{\nu}_2$ and the irradiances of the two radiations are sufficiently large, then inter alia coherent radiation of wave number $\bar{\nu}_3$ can result.

$$\bar{\nu}_3 = \bar{\nu}_1 + (\bar{\nu}_1 - \bar{\nu}_2) \quad \text{———} \quad (1)$$

Here mixing implies spatial and temporal coincidence of the two beams. If $\bar{\nu}_1$ is kept fixed (say monochromatic) and $\bar{\nu}_2$ is varied so that the condition

$$\bar{\nu}_1 - \bar{\nu}_2 = \bar{\nu}_M \quad \text{———} \quad (2)$$

is achieved where $\bar{\nu}_M$ is some molecular wave number of the system then

$$\bar{\nu}_3 = \bar{\nu}_1 + \bar{\nu}_M \quad \text{———} \quad (3)$$

Thus $\bar{\nu}_3$ is coincident in wave number with stokes Raman Scattering associated with the molecular wave number $\bar{\nu}_M$ when excited by radiation of wave number $\bar{\nu}_1$. Radiation produced in this way is termed as coherent anti–stokes scattering (CARS) to emphasize its different origin and properties. The usefulness of the techniques are highlighted as below.

(1) Conversion efficiency of $\bar{\nu}_3$ is several orders greater than the normal Raman effect.

(2) $\bar{\nu}_3$ from CARS is highly collimated and hence the collection efficiency is very high.

(3) Fluorescence and thermal radiation from hot samples can be eliminated using spatial filtering technique.

(4) No dispersion device is needed.

(5) The power associated with CARS depends on the (a) square of the normal Raman scattering cross section (b) square of the number of molecules.

(6) (i) Useful in flame iagnostics as a spatial probe.

(ii) In the study of biological chromophores through pure rotation spectra.

(iii) An important tool for molecular structural studies.

Raman Induced Phase Conjugation Spectroscopy

In order to study optical Raman spectra of transient meida, hot meida, or static media exhibiting strong fluorescence, or to obtain, spectral resolution greater than 1 cm^{-1}, one generally employs some form of coherent Raman spectroscopy (CRS). Most widely used CRS techniques employ two coherent sources, whose frequencies are seperated by nearly the Raman excitation frequency. As explained earlier SRS, CARS, and Raman induced Kerr effect (RIKE) are of the above category. RIKE is a version Raman spectroscopy that makes use of defined input and output polarizations. When a Raman-active medium is simultaneously irradiated by two exciting radiation sources, namely an elliptically polarized wave and a linearly polarized stokes wave or anti–stokes wave, the nonlinear–linear third order interaction gives rise to a new stokes wave or anti–stokes wave that is polarized perpendicularly to the wave originally incident on the medium. This phenomenon exhibits resonance if the difference in two exciting radiation frequency is near one of the Raman active molecular frequency. The signal in the spectral region of nonlinear resonance is determined on the one hand by the polarization properties of the elliptically polarized laser light and on the other hand by the resonant and nonlinear resonant terms in the nonlinear susceptibility. A circularly polarized laser beam leads to a background free Raman spectrum if one of the exciting radiation sources is being tuned or if broad band irradiation is used. The first studies of this "pure" RIKE were performed with organic liquids. Compared with other methods of active Raman scattering, the advantage of RIKE is that the phase matching condition in isotropic media is satisfied in a broad band spectrum so that under fixed excitation geometry, spectral tuning can be achieved. RIKE with an elliptically polarised laser beam proves to be an appropriate polarisation-spectroscopic method for determining optical material parameters.

Another new CRS technique employing coherent sources at only two frequencies is known as Raman in-

duced phase conjugation technique (RIPC). This is a form of four wave mixing in which two beams at ν and $\nu-\nu_1$ (or at $\nu+\nu_1$) mix with a third beam at ν to generate a fourth beam at $\nu-\nu_1$ or at $\nu+\nu_1$. The generated beam is nearly phase conjugate to one of the beams at ν.

The effect so studied has the following characteristics

1. The Raman signal is generated as a coherent beam which is nearly phase conjugate to one of the incident beam (2) Upto 16 independent combinations of beam polarisations are possible (3) The Raman signal beam is not coincident with any input beam (4) Phase matching among the four beams can be achieved for excitation frequencies in a wide range many hundreds of cm^{-1} for a given beam geometry (5) Phase matching among the four beams can also be achieved for given beam frequencies, for a wide range of input or image beam angles, thus allowing an enhanced or altered phase conjugate image at Raman resonance. This spatial resolution can be used to enhance spectral resolution or to focus on a particular region of the sample (6) The wave vectors of the excitations observed in RIPC are nearly $(2\nu \pm \nu_1)$ n/c where n is the refractive index (7) If the input beam containing $\nu \pm \nu_1$ is broadband, and beam polarisation are properly adjusted, only Raman-shifted frequencies will be conjugated and the usual nonlinear-resonant component will be absent. These properties allow Raman spectra to be recorded with single nanosecond pulses. RIPC is the latest very useful Raman technique in special situations such as for hot, birefringent and slightly tremulous media.

The Amazing World of the Honey Bees

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Honey bees have always fascinated mankind. We have clear references to them in ancient Indian and Chinese scriptures and Aristotle has much to say about them. Our fascination for the honey bee has been described by William Morton Wheeler, one of the greatest students of social insects of this century, in the following words:

"Its sustained flight, its powerful sting, its intimacy with flowers and avoidance of all unwholesome things, the attachment of the workers to the queen – regarded throughout antiquity as a king – its singular swarming habits and its astonishing industry in collecting and storing honey and skill in making wax, two unique substances of great value to man, but of mysterious origin, made it a divine being, a prime favourite of the Gods, that had somehow survived from the golden age or had voluntarily escaped from the garden of Eden with poor, fallen man for the purpose of sweetening his bitter lot".

Bees, which evolved from other insect ancestors about 70 million years ago, exist today in about 20,000 different kinds or species, as these kinds are called. Most have not the least resemblance to the honey bee and lead a solitary life. Many are social to varying degrees but none have reached that pinnacle of social evolution achieved by the honey bees. Of the honey bees themselves there are four species namely, *Apis mellifera* which occurs as a native in Europe, Western Asia and Africa, but has been distributed by man throughout the world, *Apis cerana*, formerly called *Apis indica*, which occurs in Asia including China and Japan, *Apis dorsata*, the familar large rock bee and *Apis florea*, the tiny bee which nests routinely in our gardens, the latter two species being restricted to southern Asia. Most of the scientific information on honey bees however comes from studies on *Apis mellifera* – a familiar sad tale about the neglect of natural history in the tropical regions.

The most important thing about the honey bees is of course that they are highly social. They live in large groups, in intricately organized societies and cannot survive alone. A typical hive consists of a single queen bee, the only reproductively fertile female in the colony, anywhere from 10 to 50 thousand sterile female worker bees and about 500 to 1000 males or drones, all of the latter being reproductively fertile. The home of the honey bees is the nest, an architectural masterpiece consisting of tens of thousands of hexagonal cells entirely made of wax secreted by tiny glands in each worker's abdomen. How so many different bees working simultaneously and with neither the benefit of learning nor that of a foreman, can produce such a perfect structure is a mystery that will take decades if not centuries to unravel.

Life in the nest is more intricately organized than we fellow social creatures can ever believe, let alone achieve. The queen is an egg laying machine and a chemical factory. She is capable of laying upto 3000 eggs per day and, as one may imagine this keeps her occupied day and night. The only other thing she does can fortunately be done simultaneously and that is to keep releasing a host of chemicals that will guide, instruct or prevent the worker bees from performing various tasks as appropriate. When the eggs hatch, the hive would be any mother's nightmare with 10,000 or more hungry mouths to feed. But the worker bees are perfect match to this task, feeding every larva more than once a minute and, incredible as

it may seem, appropriately changing the quality and quantity of food depending on the age, sex and future caste of each larva. If this is mind boggling to the layman, it is even more so to the scientist, for it is not even clear how one formulates the right questions to begin to understand this challenge of nature to our intelligence.

The honey bees and their relatives have achieved to perfection what we humans are still struggling to do. Choosing the sex of their offspring is a simple matter to them. Firstly, the honey bee queen does not need to mate everytime she produces an offspring as most higher animals have to. She mates during just one period in her lifetime but with a dozen or so males, one after the other. Having securely stored millions of sperm from each of her mates inside her body in a tiny organ called the spermatheca, she returns to the hive well equipped for a life time career in egg laying. But this is not the end of the story because nature's mysteries never cease. In spite of having all these many millions of sperm in her body, she may choose to lay unfertilized eggs. These unfertilized eggs always develop into males while females are produced from fertilized eggs. With voluntary control over release of sperm for fertilization she achieves perfect control over the sex of her offspring.

In addition to feeding the larvae, there are many other tasks awaiting the attention of the workers. Workers build the comb and also enlarge, shape and repair it as and when required. When a larva has completed its growth, they cap its cell and when it completes development and comes out, they trim the cappings and clean the cell preparing it to receive a fresh egg from the queen. The worker bees take turns so that at any given time the queen is surrounded by several workers, feeding her, licking her, caressing her and, we might say, inadvertently acquiring those very chemicals which will control their own behaviour. Grooming and feeding each other is another major task that engages the workers. It is because of this habit of feeding and grooming each other that chemical messages emanating from the queen are almost instantly spread throughout the colony. If the queen is removed for instance, the whole hive seems to know of this tragedy within minutes. Finally workers have to go out in search of food – their food being nectar and pollen – harvest it and store it in the hive. How is all this work coordinated? The answer seems to lie in efficient division of labour. Worker bees have age-specific duties so that at any give time each worker performs a single or a small subset of its lifetime's duties. This phenomenon called age-polyethism ensures that a worker bee begins her life as an adult member of the hive by cleaning cells. This job is done during the first two days of her life when she appears to be incapable of doing anything else. After about two days, her wax glands begin to work and now, building and nursing brood become her main tasks for the next week or so. This is followed by another change in assignment and the worker bee graduates into feeding and grooming nest-mates. At about 15 days of age, she moves towards the periphery of the hive and begins to receive pollen and nectar from incoming foragers and store these in appropriate cells. Only after she is about 3 weeks of age does a worker ever venture out of her hive to begin her tireless task of scanning her new world of about 100 sq. km in search of nectar and pollen, the prime needs of the hive. For this worker, whose journey through life we have been following, the story must end soon for, one day in the next two weeks or so she will either fall dead of exhaustion or fulfil her larger role in the ecosystem by falling prey to some bird.

Few people realize that honey bees are the only creatures in the world other than man who communicate by means of a set of arbitrary conventions

Figure 1. A portion of a colony of honeybees. In the upper lefthand corner the mother queen is surrounded by a typical retinue of attendants. She rests on a group of capped cells, each of which protects a developing worker pupa. Many of the open cells contain eggs and larvae in various stages of development, while others are partly filled by pollen masses or honey (extreme upper right). Near the centre a worker extrudes its tongue to sip regurgitated nectar and pollen from a sister. At the lower left another worker begins to drag a drone away by its wings, the drone will soon be killed or driven from the nest. At the lower margin of the comb are two royal cells, one of which has been cut open to reveal the queen pupa inside (original drawing by Sarah Landry. Reproduced from the insect societies by E. O. WILSON, Harvard University Press Copyright © 1971 by the President and Fellows of Harvard College.

that may be called symbolic language. It is not uncommon for a worker bee to suddenly encounter a large tree in bloom offering several thousand times the quantity of pollen and nectar that she can carry back to her hive in one trip. Honey bees would never be able to maintain such large populations of young and adults in their hives if it were not for their unique capacity to fly back home and inform their nestmatess of their find and thus bring hundreds if not thousands of them to the spot within a few hours. It took

many years even for scientists to accept that a honey bee worker can, by means of the dance language, convey to her fellow workers the distance and direction from the hive of a new source of food. This amazing chapter in the mysteries of nature was discovered by Karl von Frisch who was rightly honoured with the Noble prize for his momentous discovery. When a worker bee finds a source of food close to the hive, she returns home, releases a scent to attract the attention of other bees and performs the "round dance" by simply running repeatedly in circles. the bees following her and running behind her decode this message to mean "there is food nearby, go and find it". Equipped with some clue about what the dancer might have found provided by the smell of pollen sticking to the dancer's body, the dance watchers fly out and systematically scan the surrounding 100 square meters or so of their hive for that kind of food.

But when a worker bee finds food, say about 2 km away from the hive, it is not much use coming back and telling her nestmates "there is food, go and find it". So now she performs a very different kind of dance called the waggle dance in which she rapidly runs on the surface of the comb either facing straight up, straight down, or at some angle to the vertical, wagging her abdomen and at the end of this she runs back swiftly to the position where she started without shaking her abdomen and repeats the whole process over and over again. The bees following and running behind her now decode this message in a much more sophisticated manner. The smell of pollen or nectar sticking to the dancer's body will once again tell them what to look for, the number of seconds for which she performs the waggle each time tells them the distance of the food from the hive and more importantly, the angle between her waggle run and the vertical (gravity) corresponds to the angle between the sun, the hive and the food source. Equipped with this information, the dance followers can home in within a few meters of the food source. The more one thinks about this, the more remarkable it seems. The bee must somehow measure the angle between the food, the hive and the sun and remember it. The task is made even more difficult because the bee has not flown straight from the hive to the food. Instead, she has taken a long meandering trial and error pathway and accidentally chanced upon the food source. Yet by recording every little turn she had made during the search flight into a supercomputer–her tiny little brain about the size of a pinhead–she is able to instantly calculate what the angle would have been if she had flown straight to the food source. But she has to do more than that on reaching the hive. She must use that angle to orient her body with respect to gravity while dancing. As it happens, her behaviour is more remarkable still. The sun's position she "knows" keeps changing and an hour may have elapsed since she last saw the sun. Incredible as it may seem, she makes corrections in her calculations and dances at an angle that corresponds to the present position of the sun which she has not seen. The dance followers too, if prevented from going out immediately after watching a dance can correct for the changing position of the sun and fly out to the correct spot. Is there any doubt that the honey bees can perform more sophisticated calculations than any untrained and many trained humans are capable of?

Figure 3. Dancers and their followers. A – Round dance and B – Waggle dance (Reproduced from Ethology by Gould, J. L., W. W. Norton and Company, 1982)

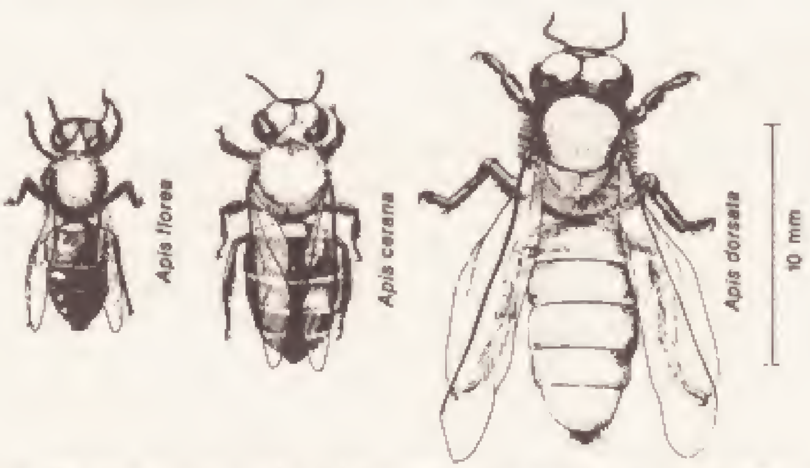

Figure 2. Workers of the three tropical Asian species of honey bees (Reprinted from the Ecology of Temperate and Tropical honey bees societies by T.D. Seelay, *Am. Scient.* 71, 264–272, 1983).

Let us now get back into the nests and help ourselves to a different kind of mystery. How are new hives produced? Workers are in plenty and can be partitioned but there is only one queen and we need at least one more to produce a new hive. That brings us to the question of how queens are produced. Any larva that is fed on a special diet consisting mainly or entirely of secretions from the hypopharyngeal and mandibular glands of the workers, called bee milk or, more appropriately, royal jelly, will develop into fertile queens. The diet of a larva destined to be a worker consists of a very small quantity of royal jelly and that too only at the very begining of her larval life for, she will soon be weaned on to a mixture of pollen and honey or the so called bee bread. So the control must be in the hands, or more correctly in the mouths of the workers! True, but the master control is still very much in the hands or again in the mouth of the queen whose mandibular glands produce a substance that chemists find it easy to call by the name 9-keto-trans-2-decenoic acid but lesser mortals prefer to call by the name "queen substance". As long as a threshold concentration of the queen substance is maintained in the hive, workers are, as if by magic, prevented not only from feeding the queen producing diet to any larva but even from constructing the special large royal cells needed to house queen-destined larvae in the first place. But when the queen dies or is weak or when she "desires" to produce new queens – for that must be her ultimate goal – the concentration of the queen substance drops and the workers get busy constructing royal cells at the bottom of the comb and later when the eggs laid in these cells hatch, in feeding them royal jelly.

HIGHLIGHTS OF THE NEXT ISSUE

Some reflections on the life and Science of Sir C. V. Raman.
Dr.G. Venkataraman

Genetic Consequences of marriage among close relatives
Prof. N. Appaji Rao

Scientific Quotations

When the new queen completes her development, in what must appear to us as an outstanding example of a mother's concern for her daughter's welfare, the old queen leaves the hive with all its wax, honey and brood and departs with a few thousand workers to find a new place and build a new hive all over again. But we should be cautious in interpreting nature. The old queen leaves just a little before her daughter comes out of her pupal case. This is achieved through communication between the mother queen and her yet to be born daughter by means of sounds they both produce. the mother seems to ask "are you quite ready to come out, shall I leave?" and the daughter seems to say "not quite yet" or "oh! yes, please be sure to leave before I come out". But why all this fuss? Because, if the two queens,

Figure 4. The Waggle dance orientations illustrated for three different positions of the food source. When the food is in the direction of the sun as in I, the dance is directed upwards and if the food is in the direction opposite to the sun the dance is directed downwards. When the food is 80 degree to the left of the sun, the waggle run is oriented 80 degree to the left of vertical. (Reproduced from Ethology by Gould, J.L., W.W. Norton and Company, 1982)

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mother and daughter, happen to meet, all parental instincts disappear into thin air and they fight each other until one of them dies. Such is nature's way of ensuring that there would never be two queens in a hive. Even if the mother has departed before the daughter's arrival, the new queen's first job is still a macabre one. Workers normally rear not just one but a few larvae into queens to ensure that at least one of them successfully develops and takes charge of the colony. The queen that emerges first systematically searches for and kills all her remaining, as yet unborn sister queens.

While all this is going on the old queen and her swarm of workers have settled on a branch or some safe place not very far away. From this swarm dozens of scout bees go out in all directions in search of a suitable site to build a new hive. Having found one they return and begin to advertize their find by using the same dance language that foragers use to communicate new food sources. But here there is one problem. If many foragers dance to indicate many different sources of food, the hive has enough workers to send to each site. But now all the bees have to go to a single new site to build their hive. In what must either be the closest that insects have come to acquiring intelligence or in what must be one of the most complicated forms of instinctive programming, the bees somehow come to a consensus and the whole swarm flies to the agreed site.

The amazing world of honey bees provides an endless series of fascinating and often mind-boggling stories but if one were forced to choose one above all the others it surely would be the worker bee's sacrifice for her colony. Valour, bravery, sacrifice and kindness are undoubtedly the hallmark of the human species but it would be a grave mistake to think that we represent the pinnacle of altruism. That distinction clearly goes to the honey bee and its relatives in the magnificent world of social insects. Not only do worker bees spend their entire life striving for the welfare of the colony and die without reproducing, but they often commit suicide to protect their colonies. There must be few amongst us who have not experienced the quick, unhesitating sting of the honey bee and yet not many of us realize that the sting of the honey bee is a marvel of nature. It is armed with barbs pointing backwards so that when firmly lodged in the offender's skin it cannot be withdrawn. When the bee attempts to fly away after stinging, the sting, the poison gland and a good part of the bee's digestive system are torn away and remain hanging onto its victim. This certainly ensures that sufficient bee venom is injected into the victim but for the worker bee it is certain death. It is unlikely that bees think or have feelings. But that they can behave in the way they do without the benefit of thought or feelings is an even greater sobering thought for some one who likes to wonder about how nature programmes animals to behave.

Further Reading

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